



# **CELLULAR V2X COMMUNICATIONS TOWARDS 5G**



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## EXECUTIVE SUMMARY

The automotive industry is evolving toward connected and autonomous vehicles that offer many benefits, such as improved safety, less traffic congestion, less environmental impacts and lower capital expenditure. A key enabler of this evolution is vehicle-to-everything (V2X) communication, which allows a vehicle to communicate with other vehicles, pedestrians, road-side equipment and the Internet. With V2X, critical information can be exchanged among vehicles to improve situation awareness and thus avoid accidents. Furthermore, V2X provides reliable access to the vast information available in the cloud. For example, real-time traffic, sensor and high-definition mapping data can be made available, which is useful not only for today's drivers but will be essential for navigating self-driving vehicles in the future.

The paper's first section describes the current status of V2X, with a focus on the Americas region. It also provides insights into how emerging 5G technologies will accelerate the realization of advanced V2X communication to improve transportation experience and quality of life. For example, 5G-based V2X is expected to enable very high throughput, high reliability, low latency and accurate position determination use cases. Some of the use cases will involve 5G working in tandem with other technologies including cameras, radar and lidar. *Cellular V2X Communications Towards 5G* describes these use cases, starting with the advanced driving categories identified in 3GPP, including ranging/positioning, extended sensors, platooning and remote driving. The paper also describes how mobile network operators, vehicle manufacturers, cloud service providers and regulatory bodies can work together to deliver a brand-new experience for drivers, travelers and other road users in the near future.

## 1. INTRODUCTION

Technologies for connected and autonomous vehicles are rapidly improving. The benefits for daily life are clear and widespread, including increased safety, less gridlock, reduced environmental impact and more creature comforts for drivers and passengers alike. V2X technologies are key enablers of this evolution.

The paper describes the role that 5G will play in enabling cellular-based V2X communications. V2X's evolution to 5G is clear via the 3rd Generation Partnership Project's (3GPP) "New Radio (NR)" access technologies. These services will unleash the true potential and synergy of connected and autonomous vehicles because 5G will deliver unprecedented quality of service, including low latency, enhanced broadband access and ubiquitous connectivity.

V2X communications have already been standardized by 3GPP, based on LTE Release 14, as described in the 2016 5G Americas whitepaper, [V2X Cellular Solutions](#). That technology is slated to support V2X communications for *basic safety* use cases. In current and future releases, 3GPP is working on specifying 5G technologies, and with it, 5G-based V2X. It is important to note that the 5G radio access enhancements will enable *advanced* use cases for data exchange but will not duplicate the 4G-based V2X functionality. This way, 5G V2X services are additive to the foundational capabilities of LTE V2X. Indeed, 5G will be future-proof and backwards compatible with LTE V2X.

The paper is organized as follows:

**Section 2** describes the current V2X landscape, including standards and industry status with expected V2X benefits.

**Section 3** provides details about 5G-based V2X communication, including 5G standards and impacts on the automotive sector with details around architecture, use cases and security aspects. The section also compares V2X and Dedicated Short Range Communication (DSRC) technologies.

**Section 4** explores the advanced use cases that 5G-based V2X communication will enable to accelerate the development of V2X. It also explores the 5G-based V2X impacts on various stakeholders and identifies areas of collaboration between them.

## 2. CURRENT V2X LANDSCAPE

This section summarizes the current V2X landscape in the U.S., Europe and Asia. It also discusses V2X deployment considerations and expected benefits.

### 2.1 V2X OVERVIEW

The automotive industry is in the midst of a transition toward producing vehicles that are more aware of their surroundings. For many years, there has been a goal that vehicles should be able to communicate with not only other vehicles (V2V) but also with nearby infrastructure (V2I), Internet-based networks (V2N) and even pedestrians (V2P). Collectively these use cases have become known as vehicle-to-everything (V2X) connectivity. Now, with advances in electronics, sensing technologies and computing techniques such as machine learning and computer vision, this use cases are starting to become reality. New vehicles today are capable of taking a more active role by warning drivers of potential collisions with oncoming vehicles, assisting with emergency braking and monitoring intersections, to name just a few examples. This represents a big step forward from relying on passive safety features such as seat belts and air bags.

In the automotive industry, this trend is viewed as the beginning of an evolution to automated and eventually fully autonomous vehicles. In an autonomous vehicle scenario, the vehicle's on-board computers will be fully capable of performing all driving operations on their own, with no human monitoring required. This is still a few years away, but today we are getting closer with the likes of Tesla providing partial automation and Google's self-driving car testing conditional automation.

In the U.S., the NHTSA is considering using IEEE 802.11p-based DSRC technology for V2V communications. The technology was developed specifically for V2V applications that require critical latency of ~100ms, very high reliability and security authentication with privacy safeguards. The DSRC standard was finalized in 2009 and has been subjected to extensive testing by automakers and select large-scale trials. Stakeholders have completed work on use of DSRC to protect vulnerable road users.<sup>1</sup> The Federal Communications Commission (FCC) has allocated dedicated spectrum for transportation safety applications in 1999 in the 5.850-5.925 GHz band to ensure operation without interference that DSRC-based V2V systems plan to leverage.

However, DSRC has several weaknesses. There is no apparent path for continued evolution of the radio standard to meet changing technological and consumer needs.<sup>2</sup> Additionally, as it was designed for rapid transmission of short-range basic safety messages, it is unable to meet the higher bandwidth demands of V2N applications such as autonomous driving, multimedia services. DSRC also doesn't have the bandwidth necessary to transmit the raw vehicle sensor data that will become increasingly common in automated

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<sup>1</sup> [SAE standards](#), SAE International, March 2017

<sup>2</sup> In contrast, a number of standards based on [DSRC](#) have been developed by stakeholders. See Applications development is also extensive: [https://www.its.dot.gov/pilots/cv\\_pilot\\_apps.htm](https://www.its.dot.gov/pilots/cv_pilot_apps.htm)

vehicles. DSRC also has limited range: about 300 m. For more details, see the 5G Americas whitepaper published in 2016, "[V2X Cellular Solutions](#)."

DSRC would require the deployment of tens of thousands of roadside units (RSUs) embedded or attached to roadway infrastructure to enable an effective network along the nation's roads. This is a particular challenge in more rural areas considering the vast distances involved. State highway administrations and other roadway authorities would be responsible for deploying, managing and operating the RSUs and associated infrastructure networks, such as fiber or copper backhaul. While V2V communications do not require RSUs to perform crash-warning functions, RSUs are needed for ancillary functions such as certificate revocation list (CRL) distribution, certificate top-ups and to support other longer-range V2X use cases.

LTE and 5G can be used for these RSU functions thereby eliminating the need for highway authorities to install and maintain RSUs. That highlights another key disadvantage for DSRC: The need for another set of radios when all new vehicles already come with embedded cellular radios. By using cellular technologies for both short and long-range use cases, OEMs can reduce vehicle bill of materials (BOM) costs while meeting or even exceeding the safety requirements.

Beyond a technology comparison, however, there are other policy considerations that will need to be resolved for LTE-based V2X to be embraced by stakeholders. These include the universal availability of V2V or other safety-related applications for vehicle owners that choose not to activate their mobile network operator SIM card for cost or privacy reasons, a revised set of liability issues and the ability of state highway authorities to interface with an LTE network that they do not operate.

Recently, attention has also been focused on cellular LTE technology which is quickly evolving to meet the needs for V2X communications. The current LTE standard in 3GPP Release 13 is not capable of meeting the low-latency and high-speed requirements of safety-critical V2V applications. Also, vehicles in areas with poor or no network coverage would be unable to communicate with each other. Despite these limitations, LTE Release 13 is capable of meeting some of the less stringent V2N use cases today. However, the completed 3GPP Release 14 LTE standard does include support for cellular-V2X (C-V2X) use cases, enabling cellular technology as an additional option for the majority of V2X applications. With LTE Release 14, direct device-to-device communication improves latency and support operation in areas without network coverage and at high relative speeds, while network broadcast capabilities can help to meet other V2X requirements. In addition, the ability to leverage existing cellular infrastructure, with its broad coverage footprint, would reduce costs and accelerate the realization of the safety and efficiency benefits of V2X communication.

As U.S. regulatory agencies look toward finalizing proposed legislation and the details behind V2X communication, the planning for and implementation of V2X services in Europe is progressing along a different path. In April 2015, the European Parliament passed legislation requiring all new cars to be equipped with eCall technology,<sup>3</sup> which is the ability to automatically dial Europe's single emergency number in case of an accident. The law requires every new vehicle produced after April 2018 to be equipped with integrated cellular technology, thereby seeding the vehicle base with cellular-capable vehicles. To address vehicle connectivity, the European Commission adopted a coherent strategy<sup>4</sup> in 2016. The strategy aims to promote an integrated European market that supports common priorities and would leverage both cellular communications and European Telecommunications Standards Institute - Intelligent Transport Systems - G5 (ETSI ITS-G5), a standard based on IEEE 802.11p and similar to DSRC. Spectrum resources

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<sup>3</sup> European Commission, "[eCall in all new cars from April 2018](#)"; April 2015.

<sup>4</sup> European Commission, "[An EU strategy on cooperative, connected and automated mobility](#)"; November 2016.



for V2X communication in Europe have been allocated in the 5.9 GHz band, similar to the U.S. The strategy outlined by the European Commission will serve as the foundation for implementing the necessary legal framework in 2018 that will enable the commercial deployment of cooperative intelligent transportation systems by 2019.

A more fragmented approach is playing out in Asia. China plans to decide on unified standards for V2V and V2I communication in 2018,<sup>5</sup> an important step given the country's large population and growing global economic importance. In contrast, in Japan, Toyota introduced vehicles capable of V2V and V2I communication using DSRC back in 2016<sup>6</sup> and continues to develop more advanced capabilities.<sup>7</sup>

Japan's DSRC uses a different band (760 MHz) and a different standard (Association of Radio Industries and Businesses ARIB STD-109). It is still based on IEEE 802.11p but differs substantially in the physical layer. Korea has also focused significant attention on the testing of automated vehicles as of late, with the hope of deploying some automated vehicles for the 2018 Olympics in Pyeongchang. Korea has also designated spectrum in the 5.9 GHz band for intelligent transportation systems.

These differences around the world illustrate that there are strategic planning and deployment choices to be made. The C-V2X 3GPP standard was completed in March 2017,<sup>8</sup> with products underway. Table 1 compares DSRC, Release 14 C-V2X and 5G C-V2X at a high level.

**Table 1. High-Level Comparison of Attributes for DSRC, LTE V2X and 5G V2X.**

KEY ELEMENTS	DSRC/ IEEE 802.11	Rel 14 C- V2X	5G C-V2X (Rel 15,16) (expected)
Out-of-network operation	✓	✓	✓
Support for V2V	✓	✓	✓
Support for safety-critical uses	✓	✓	✗*
Support for V2P	✓	✓	✓
Support for V2I	<i>limited</i>	✓	✓
Support for multimedia services	✗	✓	✓
Network coverage support	<i>limited</i>	✓	✓
Global economies of scale	✗	✓	✓
Regulatory/testing efforts	✓	<i>limited</i>	✗
Very high throughput	✗	✗	✓
Very high reliability	✗	✗	✓

<sup>5</sup> Reuters, "[China to set communication standard for driverless cars after 2018](#)"; December 2016.

<sup>6</sup> Traffic Technology Today, "[Toyota to introduce world's first DSRC-based V2X system in production cars](#)"; 2015.

<sup>7</sup> Toyota, "[V2X Systems in Japan](#)"; 2016.

<sup>8</sup> 3GPP, "[Initial Cellular V2X standard completed](#)"; September 2016.

Wideband ranging and positioning	×	×	✓
Very low latency	×	×	✓

\*Note: Rel-15 is LTE-based and supports basic safety messaging just like Rel-14 V2X. Rel-16 will include the capabilities of Rel-14 and 15 and add support for more advanced use cases via 5G NR-based V2X

LTE Release 14 C-V2X can be viewed as a necessary waypoint along the timeline for 5G development, as it supports safety-critical use cases. As 5G technology evolves, 5G-based C-V2X will be able to take advantage of the enhanced mobile broadband, ultra-reliable low-latency communication and massive-scale machine-to-machine communication, all of which will support more advanced use cases (see Section 4). For backward compatibility, a 5G V2X-enabled vehicle will support not just these advanced services, but also the basic safety for which LTE-based V2X was designed.

## 2.2 STANDARDS AND INDUSTRY

As often is the case with technology trends, standards and industry have complex interactions, as one influences the other and vice-versa. This is no different for V2X technologies.

### Communication Layer Standard Overview

On the standard side, to support V2X communication, there are two main technologies: 802.11p and cellular (LTE and soon 5G). There is also a third option—low-power wide-area network (LPWAN)—for V2I special use cases such as smart city parking. Table 2 summarizes the key standards to consider:

Table 2. Major V2X Technologies.

Technology	Region	Standard
802.11p	US	IEEE 802.11-2012, IEEE 1609.2 - .4, SAE J2735 and SAE J2945/x series
802.11p	Europe	“ITS-G5”, ETSI ITS series
802.11p	Japan	ARIB STD-109
Cellular LTE	Global	3GPP TS 22.185, TS 23.285 for V2X and LTE, and TS 36 series for radio access
Cellular 5G	Global	3GPP TS 22.186; TS 23.501 for network architecture 3GPP 38 series for the radio access

For more details about IEEE 802.11p, now known as IEEE 802.11-2012 reference [V2X Cellular Solutions](#).<sup>9</sup>

For V2N, 5G is a converged network supporting heterogeneous access to a common core (5GC), and it is expected that these different technologies will coexist with gateways to interact between the different elements. Typically, a vehicle talking 802.11p could send data to a gateway that will then connect to 4G and then 5GC, or directly to 5GC.

<sup>9</sup> [V2X Cellular Solutions](#), 5G Americas, November 2016.

A number of other standards support V2X communication networks, such as Network Function Virtualization (NFV) and Multi-access Edge Computing (MEC), both developed by ETSI and being adopted by 3GPP.

As its name implies, MEC brings the service closer to the network edge: therefore, close to the devices' point of attachment, and precisely why it becomes relevant for V2X. This technology is characterized by proximity to the wireless device, ultra-low latency and high-bandwidth support, location awareness and real-time access to network and context information.

MEC standardization is being done at the ETSI MEC Industry Specification Group (ISG), with the objective of creating an open environment that can support cloud platforms at the edge, possibly spanning multiple vendors. These platforms are then accessible to service providers and third parties, including car manufacturers and application providers. MEC addresses the requirements related to latency and high throughput between the client and the server application. MEC technology is being leveraged by 5G, and it is very beneficial to multiple V2X use cases. For example, real-time situational awareness and high - definition (local) maps can take advantage of MEC due to the real-time and local nature of the information needed for accurate and augmented situational awareness of the road users.

### **Application Layer Standard Evolution**

Over the years, and with significant transportation stakeholder input, the SAE DSRC Technical Committee in the U.S. and the ETSI ITS Technical Committee in Europe have developed a set of applications and specific V2X messages. It is important to note that these standards assume the access layer to be DSRC/ITS-G5. It is natural to expect these standards can be adapted, if needed, to run atop cellular V2X, including both LTE and 5G access layers. To this end, the SAE Cellular-V2X Technical Committee is working on a new application layer standard SAE J3161<sup>10</sup>.

It is also reasonable to expect this cycle of adaptation and adoption to expand the scope of envisioned connected vehicle services. Cellular V2X is not limited to short range, ad-hoc message broadcast and reception, but instead includes a wide variety of high-bandwidth applications. Therefore, the types of messages and services enabled will likely transcend even those combinations available in SAE and ETSI. In fact, the 5G convergent network and the very existence of V2N in combination with V2I and V2V enable additional participants, concepts and spectrum, to include potential use of existing cellular systems (V2N) in tandem with LTE V2X direct messages (V2V, V2I) or short-range uplink and downlink (V2I).

The automotive industry has adopted a common framework for automated driving that was developed by the SAE. Table 3 summarizes SAE International Standard J3016's<sup>11</sup> six levels of driving automation, and the gradual handoff of execution, monitoring and fallback performance from a human driver to an automated driving system. There is no direct mapping of these levels of automation to key performance indicators for the radio/ transport layers of the communication link. Some of these levels of automation may be achievable

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<sup>10</sup> Society of Automotive Engineers, "J3161: On-Board System Requirements for LTE V2X V2V Safety Communications."

<sup>11</sup> [Society of Automotive Engineers](#), "J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Driving Systems"; 2014.



without V2V communication, while some will need V2V communication, and perhaps with more stringent requirements that 5G transport can meet.

Table 3: SAE J3016 Levels of Automation (Source: SAE International).

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
<b>Human driver monitors the driving environment</b>						
<b>0</b>	<b>No Automation</b>	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
<b>1</b>	<b>Driver Assistance</b>	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
<b>2</b>	<b>Partial Automation</b>	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	<b>System</b>	Human driver	Human driver	Some driving modes
<b>Automated driving system ("system") monitors the driving environment</b>						
<b>3</b>	<b>Conditional Automation</b>	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	<b>System</b>	Human driver	Some driving modes
<b>4</b>	<b>High Automation</b>	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	<b>System</b>	Some driving modes
<b>5</b>	<b>Full Automation</b>	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	<b>All driving modes</b>

## Industry Update

On the industry side, there are different actors: vehicle manufacturers, infrastructure providers (road, cities), network operators and the regional institutions/regulators.

As mentioned in the previous section, a number of regions have conducted extensive trials with 802.11p and adopted this technology for initial deployment of V2X. At the same time, a number of cities and infrastructure provider offer solutions with LPWAN combined with cellular in the car. Moving forward with 5G being a technology that expands the scope of use cases with one technology fits all, it is anticipated that a broader adoption of 5G cellular will occur for V2X, especially for V2I and V2N. A number of trials are ongoing around 5G, and V2X is one of the preferred use cases. This being said, the ITU and countries need to allocate 5G spectrum, operators need to deploy 5G and on-board unit (OBU) manufacturers need to evolve their existing products to support 5G New Radio (NR) when available, if the desire is to fully leverage 5G's end-to-end capabilities.

## 2.3 EXPECTED BENEFITS

5G-based V2X will enhance quality of life, safety and how we live and function in a society. This section discusses several examples of those benefits.

## Transportation Safety

Around 1.25 million people worldwide die from traffic accidents each year, and between 20 million and 50 million suffer non-fatal injuries.<sup>12</sup> In the U.S., there were some 6 million crashes in 2016,<sup>13</sup> leading to an estimated 40,200 fatalities<sup>14</sup> and more than 1.7 million injuries. The number of fatalities represents a 14 percent increase since 2014, so this clearly is a problem that needs to be addressed.

Efforts to reverse these trends and improve vehicular safety and traffic efficiency have varied around the world. In the U.S., the NHTSA has been studying V2V communication for years and issued a Notice of Proposed Rulemaking (NPRM) in January 2017 to mandate the inclusion of V2V technology in all new cars. The NHTSA believes this is necessary in order to obtain a critical mass of vehicles on the road that is needed to realize the safety benefits. Without this critical mass of vehicles, all communicating in a common language, so to speak, the benefits would be limited.

The NHTSA estimates that safety applications enabled by V2V and V2I could eliminate or mitigate the severity of up to 80 percent of non-impaired crashes, including crashes at intersections or while changing lanes.

## Traffic Efficiencies

The ability to communicate, analyze and react with V2X technology across vehicles, infrastructure and intelligent applications enables cities to provide a variety of intelligent transportation solutions. Examples include traffic flow optimization, reduced congestion, hazard protection and potential reduction in traffic rule violations.

## Infrastructure Savings

In addition to the increased vehicular safety and traffic efficiencies, 5G-based V2X technologies will provide significant savings in the capital and operational spends. The city transportation system can gather the real-time data, analyze the traffic pattern and apply deterministic traffic congestion algorithms for better road management and improved infrastructure planning.

Road weather information gathered from the various nodes of the system will be collected and analyzed by transportation management centers, allowing for advanced warnings and more efficient deployment of Department of Transportation (DoT) road crews. These benefits are expected to increase in proportion with the adoption of V2X cellular communication.

Insurance providers and their policyholders also could benefit because V2X enables more precise information gathering. For example, premiums can be based on each driver's habits and routes rather than on traditional, overly broad data such as demographics.

## Smart Green Environments

V2X technologies benefit the environment by, for example, reducing traffic jams that increase pollution. The coordination between vehicles and infrastructure also will mitigate unnecessary braking and stopping at intersections, further reducing fuel consumption and emissions.

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<sup>12</sup> World Health Organization, [Road traffic injuries](#), May 2017.

<sup>13</sup> National Highway Traffic Safety Administration, [Traffic Safety Facts 2015](#), 2015.

<sup>14</sup> National Safety Council, [NSC Motor Vehicle Fatality Estimates](#), December 2016.

In the U.S. alone, by 2060, with V2V fully deployed, the proposed NHTSA rule<sup>15</sup> is estimated to save approximately 5,631 to 7,613 fatal equivalents annually. Finally, the total associated monetized annual savings would range from \$54.7 billion to \$73.9 billion. Of these savings, \$7.7 billion to \$10.6 billion is estimated to be in the form of reduced property damage and congestion.

### 3. 5G-BASED V2X

V2X was introduced with 802.11p and supported a limited set of basic safety services. With 3GPP Release 14, V2X could expand to support a much wider, richer range of services: from low-bandwidth safety applications to high-bandwidth applications such as passenger infotainment. 3GPP Releases 15 and 16 will enable even more V2X services by providing longer range, higher density, very high throughput and reliability, highly precise positioning and ultra-low latency. Figure 1 summarizes these features and shows how 802.11p, LTE and 5G may coexist for some time, depending on the region.

## V2X Evolution

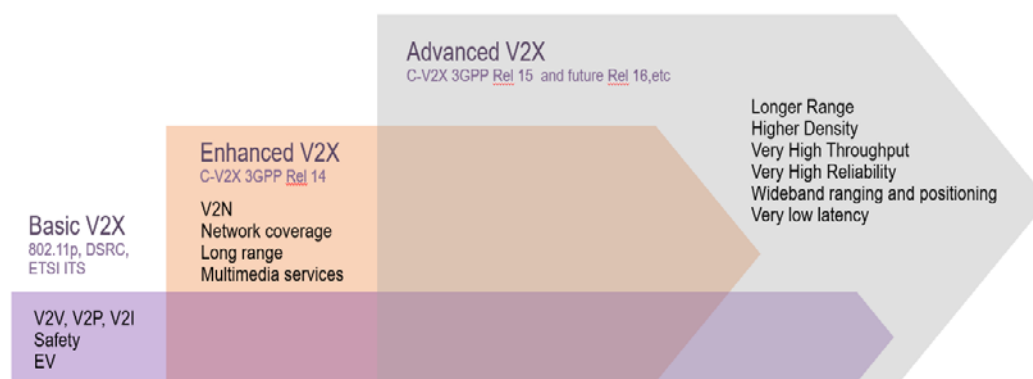


Figure 1. V2X Evolution.

### 3.1 DESCRIPTION OF 5G

5G will support a broad range of V2X and non-V2X use cases, including enhanced Mobile Broadband (eMBB), massive Internet of Things (mIoT) and mission-critical services. These use cases have diverse requirements, including high data rates for eMBB, low power consumption and high scalability for mIoT, and ultra-low latency and high-reliability communications (URLLC) for mission-critical services. Meanwhile, the ever-increasing mobile data traffic volume means that 5G must support more spectrum bands and types, from sub-6GHz to mmWave, as well as licensed, shared and unlicensed allocations. To satisfy these diverse and sometimes stringent requirements under one platform, the 5G air interface must be highly capable, with the flexibility to adapt to target use cases and spectrum. The 5G system is introduced in 3GPP Release 15. The 5G radio interface is referred to as 5G New Radio (NR). This new radio interface will support an array of advanced features such as scalable Orthogonal Frequency Division Multiplexing

<sup>15</sup> NPRM, [Federal Motor Vehicle Safety Standards: V2V Communications](#), January 2017.

(OFDM) numerology, flexible self-contained Time Division Duplex (TDD) sub-frame, massive Multiple-Input Multiple-Output (MIMO), diverse spectrum bands and bandwidth, V2X and many others. These features together deliver a radio interface with much lower latencies, enhanced reliability, higher spectral efficiency and greater data throughput.

The 5G system also is evolving toward an end-to-end infrastructure capable of delivering a consistent user quality of experience in a heterogeneous environment across a wide variety of use cases, using multi-access including 5G radio but also 3G-4G, Wi-Fi, LPWAN and fixed networks. A number of technologies are introduced, such as NFV/Software Defined Networking (SDN), Control-User Plane Separation (CUPS), MEC, network slicing, automation and Development and Operations (DevOps). These allow more flexibility and move from the current monolithic core network to a shared pool of virtual resources allocated dynamically for different types of services.

NFV, as defined by ETSI NFV, has started to be implemented in current networks. 3GPP adopted NFV to support 5G, allowing for resource sharing and dynamic scalability across compute, memory/storage and network resources. SDN is also part of 3GPP's latest specs to support CUPS and allow programmatic access to control the data flows, providing centralized control plane, lowering the cost of the network fabric and bring granularity to the per-packet level.

5G networks also will use MEC. As defined by ETSI MEC, a couple of new concepts and technologies are introduced. The first is a cloud hosting environment at the edge of the network that enables the deployment of virtualized network functions and third-party applications closer to the user and devices. Second is a set of Application Program Interfaces (APIs), mainly radio and location APIs exposed to third-party applications. Virtualization is also an important technology utilized in the implementation of MEC. The MEC hosting infrastructure consists of hardware resources and a virtualization layer. The virtualization manager provides, in brief, an infrastructure-as-a-service (IaaS) capability.

Network slicing allows network operators to define different types of services and allocate dynamically proper resources to support this end-to-end service by configuring different network segments. By using slicing technology, one physical network can be divided in multiple virtual networks, each supporting different service requirements or even different customers. Virtualization, combined with SDN and slicing, enables the network to allocate resources to different slices in a dynamic fashion and reroute dynamically the traffic through the different virtual functions of each slice. The amount of resources allocated can adapt based on traffic conditions. Moreover, traffic from one slice does not impact traffic from other slices. In addition, management of a slice can be delegated to third parties.

Last but not least, management of 5G systems will be much more automated. Starting with continuous integration/continuous delivery (CI/CD), new network functions developed by suppliers are carried over to network operators via programmatic interfaces. Next, those functions are integrated/tested and deployed in live networks through a standard automation environment that will take care of onboarding, instantiation, lifecycle management, update/upgrade and termination. This DevOps system will be associated with analytics that will collect events to monitor the network and services and provide recommendations or trigger actions to reconfigure the network automatically.

## 3.2 5G FOR AUTOMOTIVE SECTOR

Initially defined as LTE V2X in 3GPP Release 14, C-V2X is the platform for an evolution track that will enable enhancements in future releases (Release 15 and beyond) for LTE-Advanced Pro and for the 5G NR. The 3GPP standards and the cellular industry have demonstrated in the past their capability to integrate new requirements emerging from recent market experiences and needs, especially introducing those

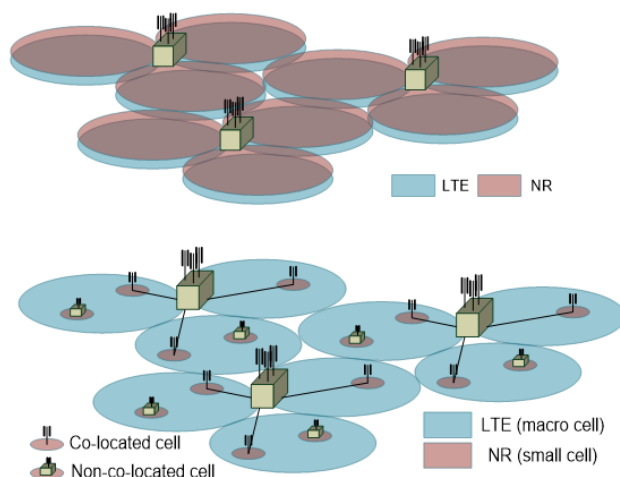
quickly into the existing standard and platforms. This evolution always maintains full backward compatibility to the previous releases of the same generation, enabling service-level interoperability between generations and releases. The backward compatibility means that even after the 3GPP network is updated to a new release, devices operating in previous releases still function properly and perform as expected—a key consideration for vehicles, which typically remain in service for at least a decade. The interworking guarantees that devices from different releases can communicate with each other. Interworking is designed for V2V direct communication and guarantees that a device that is Release 15/16 compatible is able to communicate directly with a device that is Release 14 compatible for V2X services offered by Release 14. This means that a 5G network and an LTE device are able to communicate with each other using V2V direct communication.

After considering how to map each V2V service to different 3GPP technologies, the conclusion is that Release 14 technology is only used for basic safety, while NR technology is used for other (advanced) services, so that Release 14 functionality is not duplicated or replaced. Therefore, it is expected that in the beginning of the V2X service deployment, there will be Release 14 LTE-V2X devices. Later on, the 5G UEs that support V2X services will be dual-mode UEs that support both LTE and 5G.

In order to accelerate the 5G deployment and reduce the initial investment needed by operators, most operators will take a two-phase approach to deploying 5G. Non-Standalone (NSA) operation mode, which is also known as LTE-NR dual connectivity (DC), will be adopted initially, followed by standalone (SA) operation. There are several NSA options being worked on by 3GPP. In option 3, the 5G Radio Access Network's (RAN's) control plan is hosted by the LTE eNode-B (eNB). This is the most likely NSA architecture to be standardized in Release 15 and first to be deployed in the field. Figure 2 illustrates this type of deployment.



# Cell Layout- NR and LTE Coverage co-exist



**Figure 2. Cell Layout where 5G NR and LTE Coverage Coexist.<sup>16</sup>**

Utilizing this approach, C-V2X will quickly incorporate the 5G NR features, providing high throughput, wideband carrier support, ultra-low latency and high reliability. 5G NR V2X will also feature direct communication (therefore, V2V) using advanced radio technologies such as massive MIMO and beamforming. This evolutionary path toward 5G enables advanced V2X use cases. As operators start upgrading their core networks to a new 5G Core network (5GC), the devices operating in network-supported communication (therefore, V2N, V2I) will benefit from the network architecture advances such as vertical slicing and MEC support.

## 5G Latency and Reliability Requirements

The requirements for 5G automotive sector have been addressed by multiple standards bodies and organizations, such as 3GPP,<sup>17</sup> 5G-Public and Private Partnership (5G-PPP)<sup>18</sup> and Next Generation Mobile Networks Alliance (NGMN).<sup>19</sup> The 5G Automotive Association (5GAA) is also in the process of finalizing such requirements. There are some minor differences in the requirements, especially regarding latency. At this point, the 5G system is being engineered to support 10 milliseconds (ms) latency end-to-end (to/from the application layer) and 1 ms over-the-air for ultra-low latency design.<sup>20</sup> Reliability is also important, targeting 99.999 percent for ultra-reliable transmissions. Currently 3GPP is evaluating which service

<sup>16</sup> 3GPP TR 38.804

<sup>17</sup> [3GPP TS 22.186](#)

<sup>18</sup> 5GPPP Whitepaper, [5G Automotive Vision](#), October 2015.

<sup>19</sup> NGMN Alliance Whitepaper, [NGMN perspective on vertical industries and implications for 5G](#), February 2015.

<sup>20</sup> 3GPP TR38.913 3GPP Technical Specification Group Radio Access Network, [Study on Scenarios and Requirements for Next Generation Access Technologies](#), (Release 14).

requirements can be met by LTE and which requirements will need 5G. This will allow a direct mapping between services and use cases into a specific radio access technology.

### Transmission Modes

Transmission of V2X messages can be done via a direct mode or infrastructure mode. In the direct mode, two or more mobile devices communicate directly with each other without network assistance. In the infrastructure mode, devices communicate with the network or infrastructure. The messages sent to the network may be intended to a V2X application server or may be intended to other devices nearby, in which case the network will forward the packet to the devices in a larger area.

### Architecture

3GPP SA2 group has started to work on Release 15 and 5GC architecture, as depicted in Figure 3. This work introduces some major changes, such as a service-based architecture with user plane/control plane split and some new network elements.

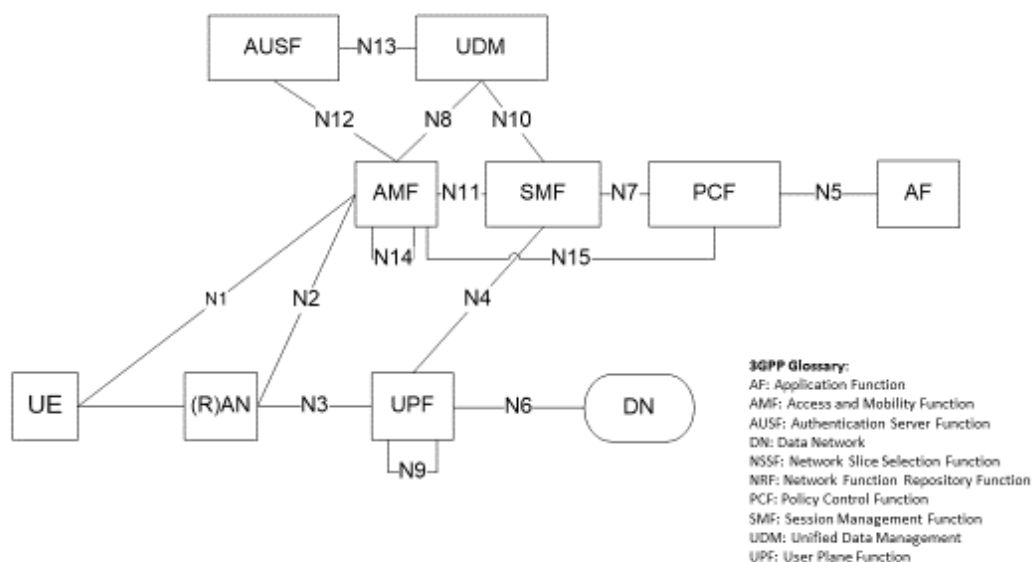


Figure 3. 5G Core Network Architecture.<sup>21</sup>

Regarding V2X specifics, the evolution of 3GPP TS 23.285<sup>22</sup> Release 14 V2X architecture had not been discussed before the end of 2017. Consequently, there are no standards definitions for how the V2X functions, such as V2X control function and V2X application server or V2X interfaces and protocols, will evolve with 5G.

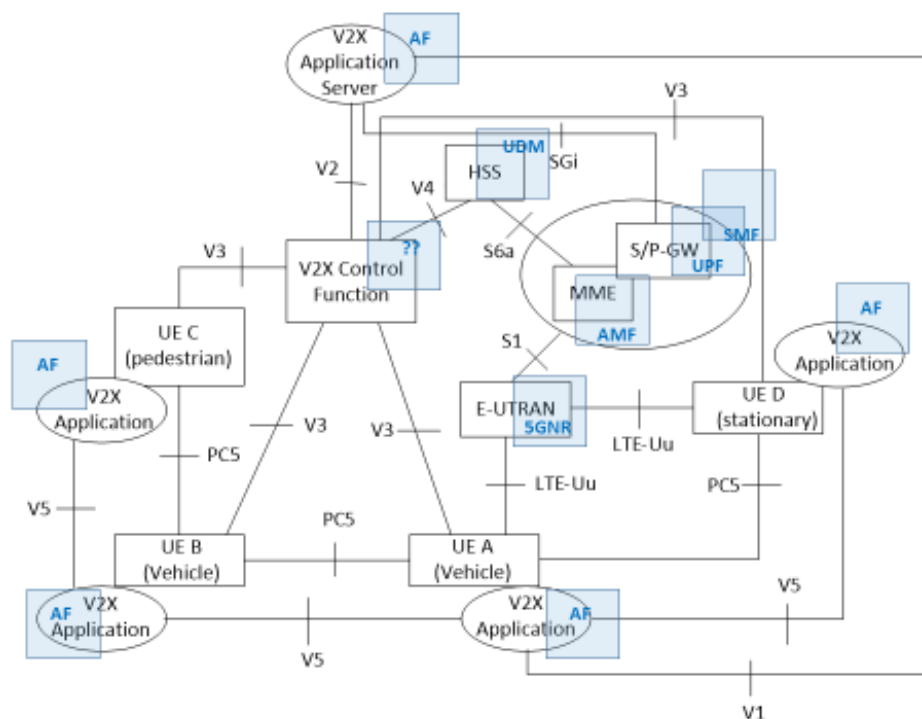
Typically, the V2X control function is used to provision the subscriber vehicle device with necessary parameters in order to use V2X communication: Public Land Mobile Network (PLMN) specific parameters that allow the device to use V2X in this specific PLMN, or parameters that are needed when the device is

<sup>21</sup> 3GPP TS 23.501

<sup>22</sup> [www.3gpp.org/DynaReport/23285.htm](http://www.3gpp.org/DynaReport/23285.htm)

not served by the cellular network. The V2X application server is an application server dedicated to V2X applications.

Based on the key 5GC network elements introduced in 3GPP TS 23.501, Figure 4 illustrates the potential V2X architecture evolution.

Figure 4. Anticipated V2X Architecture Evolution to 5G Based on Release 14.<sup>23</sup>

Some of the 4G functions, for example, Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (E-UTRAN), Mobility Management Entity (MME), Serving / PDN Gateway (S/PGW), Home Subscriber Server (HSS), would evolve naturally to the 5G architecture with 5G NR, Access and Mobility Function (AMF), Session Management Function – User Plane Function (SMF-UPF) and Unified Data Management (UDM), while a V2X application server becomes an Application Function (AF) in the 5G architecture terminology. This function can be part of the operator network or be in the domain of a third party. Similarly, as 5G core network design is progressing, the V2X CF of Release 14 will have to be integrated into the architecture.

## Network Slicing

V2N and communication via the network are typical use cases for network slicing. For instance, autonomous driving or safety/emergency services would require a Ultra-Reliable Low Latency (URLLC) network slice. Meanwhile, some auxiliary/comfort or personal mobility services would require either a best-effort slice or an eMBB slice in the case of streaming infotainment video. A given vehicle could access different slices at the same time, with passengers watching an HD movie while a see-through application detects a road hazard and triggers an emergency message for the cars behind or nearby to slow down or stop to prevent an accident. Figure 5 illustrates this scenario. The slices could come from one ‘device’ or

<sup>23</sup> 3GPP TS 23.285

multiple devices. In the case of one device, as illustrated in Figure 5 below, 3GPP defined that a given device can support up to eight different slices with a common AMF for all the slices and a SMF per slice. In Figure 5's example, there are three network slices attached to the same device and sharing the same AMF instance. Slice No. 1 is mMTC and sends data to the core and the data network. Slice No. 2 offers caching at the edge, while slice No. 3 offers access to an edge V2X application.

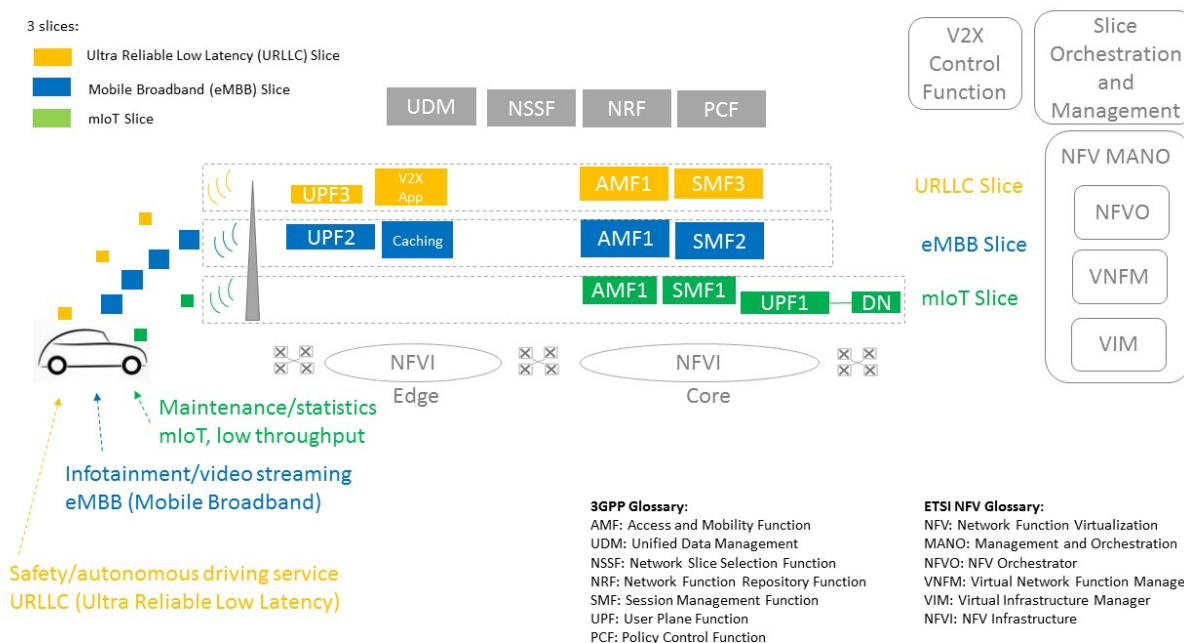


Figure 5. V2X Network Slicing Example.

## Out-of-Coverage Operation

C-V2X can operate outside of network coverage using direct communication without requiring provisioning of a Universal Subscriber Identity Module (USIM). To enable USIM-less communication, automobile Original Equipment Manufacturers (OEMs) will pre-configure the vehicle device with parameters necessary for out-of-network operation, including:<sup>24</sup>

- Authorization to use V2X
- A list of authorized application classes and the frequencies to use for them
- Radio parameters for use on direct link
- Configuration for receiving V2X messages via cellular broadcast, for example, Multimedia Broadcast/Multicast Service (MBMS)

Direct USIM-less communication allows C-V2X to support critical safety services when network coverage is unavailable or if the vehicle doesn't have an active cellular subscription. These parameters can also be securely updated, if needed, by the OEM just like any other updates. Vehicle OEMs and mobile operators can work together to ensure the parameters they each provision are compatible, resulting in harmonious operation of various vehicle devices using the direct link in an area.

<sup>24</sup> Based on 3GPP TS 23.285, v 14.4.0, Sept 2017. Discussion on 5G C-V2X USIM-less operation has not started as of December 2017.

## 5G C-V2X as a New Sensor

Release 16 C-V2X will incorporate 5G NR design features to enable new use cases for automated driving with more stringent requirements. 5G NR based C-V2X will deliver higher throughput, lower latency and better reliability. In addition to broadcast communication, 5G NR C-V2X will be enhanced to support both unicast and multicast. It will also enable wideband ranging and positioning to deliver more precise (for example, sub-meter) location accuracy.

With these enhanced capabilities, 5G C-V2X will become a new type of sensor with ultra-long-range and high accuracy by leveraging vehicles as moving sensor platforms. For example, in a typical “see-through” use case scenario, a vehicle following a large truck with limited forward visibility can receive high-quality, real-time video feeds from cameras installed on the trunk or other nearby vehicles to gain visibility.

In another example, a cloud-based sensor analytic platform can be established to deliver visibility and accuracy unrivaled by traditional standalone sensors that operates only under line-of-sight conditions. Using 5G C-V2X, this cloud sensor platform can collect a large volume of raw and/or processed sensor data from vehicles in a region. The data is then analyzed in real-time (for example, using artificial intelligence) to identify important objects and events and pinpoint their locations. The results are then streamed to vehicles in real-time together with other relevant data, such as an HD map.

Apart from the enhanced visibility and accuracy, this new C-V2X sensor also provides access to high quality sensor data to vehicles with less-capable on-board sensors, and thus further improves road safety.

## Security Aspects

5G security is still being developed by 3GPP for device to network communications. A Release 15 study was completed and normative phase started in July 2017. The complete 5G system will be specified in Release 16, which is expected to be complete by late 2019. The description below is based on 3GPP<sup>25</sup> specification work in progress TS33.501 [version 0.3.0, August 2017].

C-V2X security is unlikely to be updated with Release 15. However, the enhancements developed for network access and associated security aspects will apply to the network-enabled mode of communication. As for the direct mode of operation, the security design for the C-V2X<sup>26</sup> Release 14 is expected to remain unchanged, namely specifying the reuse of the application-level security already defined by IEEE for DSRC systems.

Notably, LTE Release 14 does not support vehicle identity privacy when it sends V2X traffic via the network. Architectural changes would be required to support user/vehicle anonymity from the operator. It is currently too early to tell whether the 5G core network will enable network-mode V2X operation privacy.

Security for 5G aims to:

- Define device-to-network authentication methods and transport
- Specify provisioning and storage of 3GPP credentials for devices
- Specify network functions and protocols necessary for secure device operation within the operation network

The model that still stands, is that all security hinges on the security relationship between device and its home operator network. In addition, secondary authentication schemes are allowed in order to support

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<sup>25</sup> [www.3gpp.org/DynaReport/33501.htm](http://www.3gpp.org/DynaReport/33501.htm)

<sup>26</sup> 5G Americas, [V2X Cellular Solutions](#), October 2016.



industrial and virtual private networks that wish to deploy their own authentication methods and credentials. With this allowance, it is possible to deploy public key infrastructure (PKI) security, where devices use a digital certificate to authenticate to the network (and likewise the network). It can be speculated this should favor V2X systems where devices are vehicles provisioned with digital certificates and wishing to access the network for V2X applications.

So far, 5G security design is being developed to achieve the following goals:

- **Enhanced subscriber/device privacy:** This is a major change from 4G LTE in that the new Subscriber Permanent Identifier (SUPI) is never allowed to be transmitted over the air in the clear. Instead, the sensitive part of the SUPI travels over the radio link protected against spoofing and tracking, which was not the case with the 4G International Mobile Subscriber Identity (IMSI).
- **Enhanced security support at the network level, along with capability for flexible authentication and authorization schemes:** A new network function is specified: the Security Anchor Function (SEAF) which maintains the security anchor deep in a network (in a physically secure location). SEAF also provides flexibility in deploying other functions (for example, AMF and SMF). In Release 15, the SEAF is collocated with the AMF.
- **Support various types of devices that have different security capabilities and requirements:** Secondary authentication enables support for non-3GPP access links and sessions authorized by third-party servers, such as for IoT, V2X and industrial automation. This functionality is related to the access control for network slices. For example, IoT devices may require different credential provisioning and authentication method. The details for this type of industrial scenarios are still being worked on.
- **Support user data and signaling encryption and integrity protection:** These features are essential for a secure system, which is why 5G supports them. A new feature is data path integrity protection, which may be especially important for certain new services (for example, IoT). There is also the potential for the user plane security to be terminated in the network instead of the base station.
- **Separate device credential management and access authentication from data session setup and management:** This split results in a separate security context between device and the AMF which is used for mobility management (therefore, only to grant the device access to the network). A different security context is established for session management, between device and an SMF, used to authorize access of the device to specific services (for example, slices or specific data networks such as corporate networks, industrial systems). This new type of access control employs a separate authentication and authorization procedure in a flexible way (therefore, based on the Extensible Authentication Protocol (EAP)).
- **Support secure slicing:** There could be several services instantiated as a network slice, each with different security requirements. The access to a slice is granted based on the primary authentication and subscription information, but this authorization is carried out by the respective SMF. This way, the access security is contained within that network slice and does not rely on the AMF, which may serve multiple slices that may have different security requirements. Moreover, an attack mounted on one slice does not result in an increased risk for an attack on a different slice of the same network.

Overall, what 5G security is achieving is increased user privacy, resistance to cyberattacks on the network and better device hardware security. This goal is achieved with stronger authentication/authorization schemes between device and network—both radio access network and core network functions—secure credential provisioning and storage on device, and new network functions that support device-to-network communications security. Figure 6 provides a high-level illustration with security components marked in

color. The device-to-core network (therefore, the AMF) signaling is integrity- and confidentiality-protected. The device link to the radio access network is also protected, likewise, for both signaling and data traffic.

The V2X system can leverage the 5G system security for vehicle device authorization, authentication and access to the network.

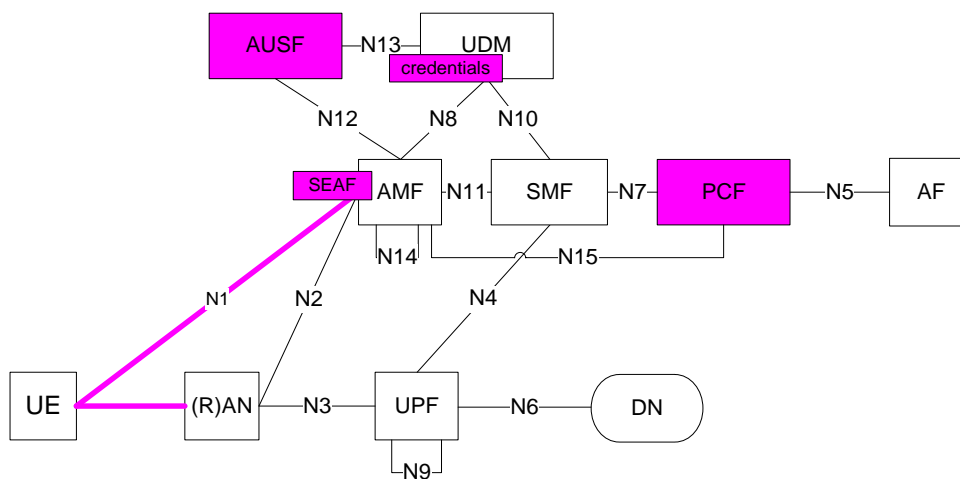


Figure 6. 5G Core Network Security Functions.

### 3.3. C-V2X AND DSRC COMPARISON

This section compares C-V2X and DSRC, with a focus on enabling vehicular safety for longer range and enhanced reliability use cases, consistent performance in congested situations and enabling advanced vehicular communication use cases.

C-V2X has several key advantages over DSRC, including:

- Longer range and enhanced reliability, resulting in enhanced safety
- More consistent performance under traffic congestions
- Evolution path towards 5G for emerging applications
- Better coexistence with other technologies

### Longer C-V2X Range and better reliability for Enhanced Safety

Based on link level simulation analysis,<sup>27</sup> C-V2X can achieve Line of sight (LOS) and non-LOS (NLOS) V2V ranges of 443 m and 107 m, respectively, compared to 240 m and 60 m, respectively, for DSRC. Longer range can be directly translated into earlier alerts and better visibility of unexpected and potentially dangerous situations. It also allows vehicles to travel at higher speeds while still being able to stop in time to avoid hazardous conditions.

Figure 7 illustrates a scenario where a disabled vehicle behind a blind curve is transmitting alerts to approaching vehicles under both icy and normal road conditions. If DSRC is used, an approaching vehicle must maintain a speed below 28 mph and 46 mph for icy and normal road conditions, respectively, to stop in time to avoid accident after receiving an alert. With C-V2X, the incoming vehicle receives the alert earlier at a longer distance away. Therefore, it can stop before reaching the disabled vehicle even if it is traveling at higher speed, (for example, 38 mph and 63 mph, for icy and normal road conditions, respectively).

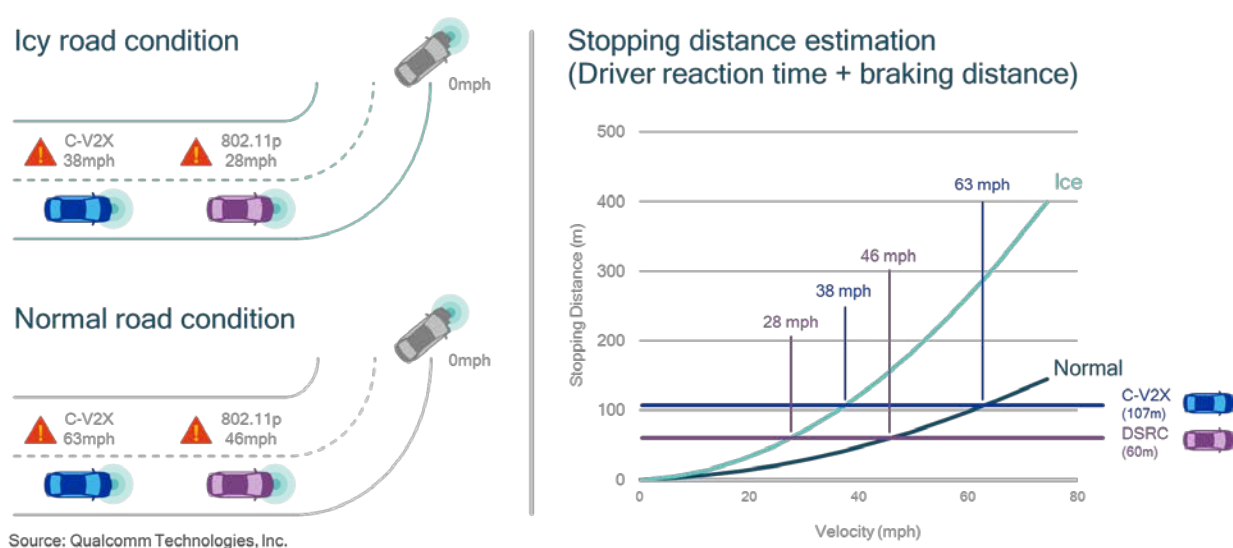
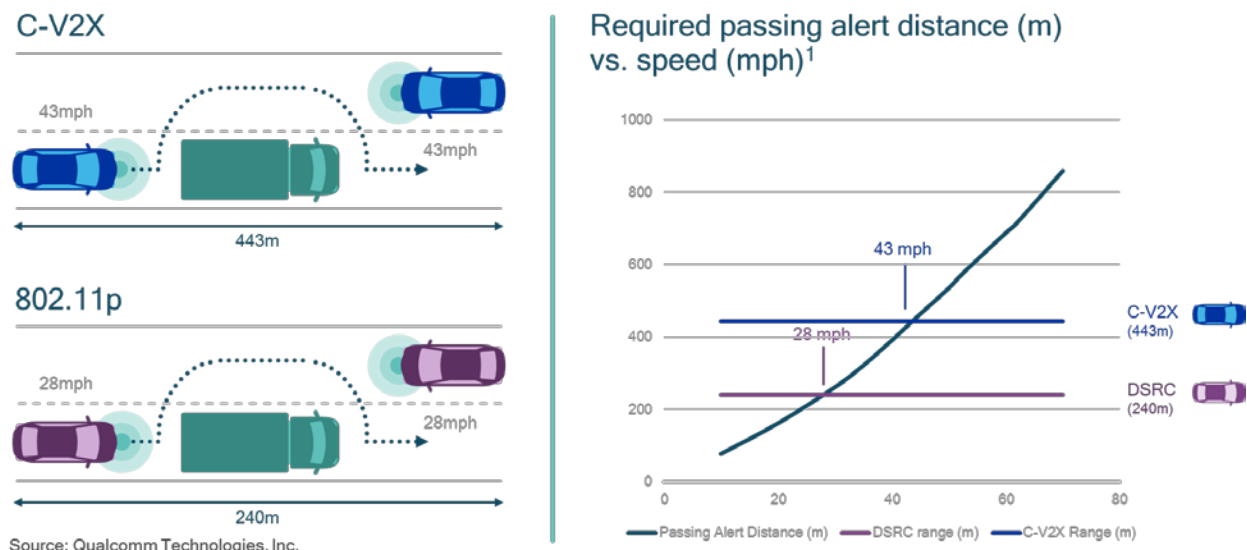


Figure 7. Disabled Vehicle after Blind Curve Use Case.<sup>28</sup>

Figure 8 illustrates a do-not-pass use case scenario where a vehicle following a large truck has limited visibility of the opposite traffic. At the same time, a second vehicle is approaching the first vehicle from the adjacent lane. The higher the vehicle speeds, the faster the two vehicles approach each other and the more dangerous is the situation if the first vehicle selected to pass the truck.

<sup>27</sup> [Accelerating C-V2X Commercialization](#), Qualcomm, September 2017.

<sup>28</sup> Stopping distance estimation consistent with CAMP Deceleration Model and AASHTO “green book”.

Figure 8. Do-Not-Pass Warning Use Case.<sup>29</sup>

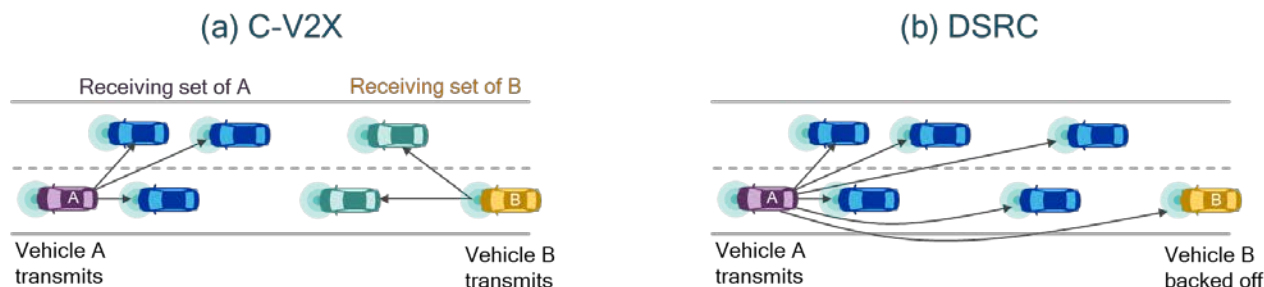
With V2V communication, the second vehicle can send warning alerts, which are used by the first vehicle to decide whether it should pass the truck. Like the first example above, the longer C-V2X range allows the first vehicle to receive the alerts earlier, thus allowing it to safely pass the truck even if it is traveling at a higher speed compared to the case when DSRC is used.

### Consistent C-V2X Performance Even in Congestion Conditions

Safety messages are generally transmitted more or less periodically for a given duration. C-V2X is designed to leverage these quasi-periodic traffic arrival patterns to deterministically pre-allocate resources for subsequent traffic arrivals. This semi-persistent scheduling mechanism ensures that resources are available when traffic arrives. There is no need to go through resource contention procedures for subsequent traffic, thus allowing C-V2X to maintain low latency even as vehicle density increases.

In addition, to improve channel access when traffic load is high, C-V2X selects the best resource, rather than the first available one, for traffic transmission. A vehicle with pending traffic first measures the relative energy levels of the available radio resource blocks averaged over a short period of time. It then ranks the radio resource blocks and selects one for transmission among those with the lowest relative energy levels. This least-energy resource selection scheme delivers better signal quality in the presence of other transmitting vehicles. Figure 9 (a) illustrates a scenario where C-V2X allows vehicles A and B to transmit simultaneously to their respective recipients. Figure 9 (b) illustrates the corresponding DSRC scenario when vehicle A is transmitting, and vehicle B backs off to avoid collision. C-V2X enables graceful degradation (decrease in range) in the face of congestion, while in DSRC, more abrupt changes in packet transmission rate occur in time, in extreme cases leading to lack of service.

<sup>29</sup> Required passing alert distance vs speed calculations based on AASHTO “green book”.



Source: Qualcomm Technologies, Inc.

**Figure 9. Least Energy Resource Selection Enables Sustained Communication with Increased Vehicle Density.**

## Evolution Path Toward 5G

Release 14 C-V2X and DSRC support low latency and reliable exchange of messages among vehicles and the infrastructure to enhance safety and efficiency. However, this is just the beginning of the evolution toward future vehicles that are expected to be increasingly autonomous with many advanced safety and non-safety functionalities. This evolution will call for additional V2X communication capabilities, such as higher capacity, ultra-low latency, ultra-high reliability, longer range and higher data rates. Continuous advancements in V2X technologies is needed to meet emerging requirements.

For example, sensor sharing is envisioned to be an important feature for future vehicles to significantly enhance vehicles' visibility beyond their immediate Line of Sight (LOS) vicinities. Sensor sharing requires the exchange of a large amount of data (for example, a series of objects or camera feeds) among vehicles and even infrastructure, and in many cases, very low latency and high reliability are necessary to ensure timeliness and accuracy of the received data. Given the expected high vehicle density in many congested urban areas, an evolved V2X technology that can support very high capacity and data rates, as well as low latency, is needed to enable sensor sharing.

## C-V2X and DSRC

While C-V2X enjoys certain link budget advantages over 802.11p, these advantages need to be tested in a high-congestion, high-traffic environment, where there may be a large number of vehicles competing for airlink resources. Performance of DSRC and C-V2X at scale needs to be directly compared to determine the efficacy of both direct communication technologies and which path makes more sense for the automotive industry to achieve optimal safety while ensuring economic viability for V2X. Even the coexistence, coordination, communication and interworking between DSRC and C-V2X could be studied to best understand the optimal safety for V2X.



## 4. ADVANCED USE CASES

This section outlines some of the advanced V2X use case categories for 5G-based communications.

### 4.1 ADVANCED DRIVING WITH INTENT/TRAJECTORY SHARING

Advanced driving<sup>30</sup> enables semi- or fully autonomous driving. Longer inter-vehicle distance is assumed. Each vehicle and/or RSU shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or maneuvers. In addition, each vehicle shares its driving intention with vehicles in proximity. The benefits of this use case group are safer traveling, collision avoidance and improved traffic efficiency.

The potential communication requirements between two vehicles employing advanced driving communications are:

- High bandwidth to support burst transmission of large quantities of data
- 10 ms latency for highest degree of automation
- 99.99 percent message reliability for highest degree of automation

### 4.2 EXTENDED SENSORS

Extended sensors refer to the ability of vehicles to obtain information about objects around them located beyond the view of their own onboard sensors<sup>31</sup>. Other nearby vehicles that can detect these objects process them, then broadcast them out to aid other vehicles around in building up a more complete picture of the road world. Overall, this provides vehicles in an area a more complete picture of the traffic environment. Current work on this aspect is taking place in ETSI ITS and 5GAA.

Extended sensors enable the sharing of raw and processed sensor data (for example, cameras, radar, lidar) among vehicles, RSUs, pedestrians and V2X application servers. The sensor data that a vehicle can share ranges from a photo of a perceived object to its real-time video stream. The availability of sensor data from multiple disparate sources enhances situation awareness of the vehicles and pedestrians, and thus improves road safety. Extended sensors also enable new features and capabilities such as cooperative driving and precise positioning, which is necessary for autonomous driving.

As an example, vehicles send messages that provide Non-Line-of-Sight (NLOS) awareness to other vehicles. This is particularly important at intersections/on-ramps, or where environmental conditions (for example, rain, fog, snow) impair the range of the onboard sensors. In Figure 19, the red car warns about the cyclist behind it, which the yellow car cannot see.

<sup>30</sup> 3GPP Technical specification TS 22.186

<sup>31</sup> 3GPP Technical specification TS 22.186

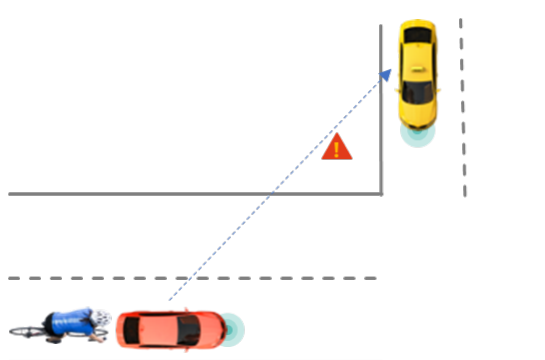


Figure 10. Intersection NLOS View.

The potential communication requirements between two V2X nodes to support extended sensors include:

- High bandwidth to support burst transmission of large quantities of data
- Less than 10 ms latency
- High message reliability of 95 percent
- High connection density to support congested areas (for example, 15,000 vehicles per mile at a congested highway intersection)

#### 4.3. PLATOONING

Platooning allows vehicles to form a tightly coordinated “train” with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency. It also improves fuel efficiency, reduces accident rate and enhances productivity by freeing up drivers to perform other tasks.

Vehicles within a platoon must be able to exchange information periodically (for example, to share status information such as speed and heading) and to send event announcements such as braking and acceleration. There are several aspects of platooning that must be supported through reliable V2V communications:

- **Joining and leaving a platoon:** to allow a vehicle to signal its intention to join or to leave a platoon at any time while the platoon is active, and to support additional signaling to complete the join/leave operations
- **Announcement and warning:** to indicate the formation and existence of the platoon so that nearby vehicles can select to join the platoon or to avoid disruptions to the platoon
- **Steady state operation group communication:** to support the exchange of platoon management messages also to indicate braking, acceleration, which road to take, change of platoon leader, etc.

Given the small target inter-vehicle distance while the vehicles are traveling at relatively high speed, V2V communication must be able to support reliable, high duty cycles and secure message exchange to ensure effective and safe platooning operation. The following are some key V2V communication requirements to supporting platooning:<sup>32</sup>

- 25 ms end-to-end communication latency among a group of vehicles (10 ms for the highest degree of automation)
- 90 percent message reliability, and 99.99 percent for the highest degree of automation

<sup>32</sup> 3GPP TS 22.186

- Relative longitudinal position accuracy of less than 0.5 m
- 10 to 30 messages per second of broadcasting rate
- Dynamic communication range control to improve resource efficiency given the varying platoon size, and to limit message distribution for privacy reasons

## 4.4 REMOTE DRIVING

Remote driving enables the remote control of a vehicle by a human operator or by a cloud-based application, via V2N communication.<sup>33</sup> There are several scenarios that can leverage remote driving, including:

- **Provide a backup solution for autonomous vehicles.** An example is during the initial autonomous vehicle deployment when a vehicle is in an unfamiliar environment and has difficulty navigating, a remote operator can take control.
- **Provide remote driver services** to youth, elderly and others who are not licensed or able to drive.
- **Enable fleet owners to remotely control their vehicles.** Examples including moving trucks from one location to another, delivering rental cars to customers and providing remotely driven taxi services.
- **Enable cloud-driven public transportation and private shuttles**, all of which are particularly suitable for services with predefined stops and routes.

Remote driving can be used in a way to lower the cost of fully autonomous driving for certain use cases because of the lower technical requirements (for example, smaller number of in-vehicle sensors and less computation requirements for sophisticated algorithms). The following are some potential V2X requirements for supporting remote driving:

- Data rate up to 1 Mbps downlink and 25 Mbps at uplink (assuming two H.265/ HEVC HD stream up to 10 Mb/s each)
- Ultra-high reliability at 99.999 percent or higher (URLLC)
- End-to-end latency of 5 ms between the V2X application server and the vehicle
- Vehicular speed of up to 250 km/h

Remote control/driving will be required when an obstacle blocks a Level 4 or 5 autonomous vehicle, rendering it unable to decide about a pathway or approach to safely navigate around it. Examples of obstacles include lanes that are blocked due to a proximate accident, double-parked cars not allowing the vehicle to pass without crossing the ingress/egress yellow lines or unexpected or never experienced situations where the vehicle is unable to make a determination on a safe action or does not know how to proceed.

When the vehicle encounters such a situation, it will stop or find a minimum risk position and then will request the assistance of a remote-control operator to take control and drive it around the obstacle. For the remote controller to understand the obstacle and determine the pathway the vehicle must take, the controller will utilize the streaming sensor information (for example, video, lidar, radar) that has been temporarily made available to him or her. Once cleared of the obstacle, the stream to the controller will cease and the vehicle will be back in full control towards its destination. This solution will require precision

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<sup>33</sup> 3GPP TS 22.186

and will need to be limited to ensure high customer satisfaction, as well as to limit the traffic impediment a stopped autonomous will cause.

## 4.5 DATA UPLINK

Automated vehicles generate upwards of 4 TB<sup>34</sup> per day from various sensors such as radar, lidar and cameras. These data sets are utilized within various stages of vehicle system development and consumer usage. During the development/trial phase, the majority of the sensor data is stored within in-vehicle storage and transported to data center platforms for developing various deep learning models, which are in turn deployed in vehicles for live object detection and classification. After the vehicle is sold, these models are periodically tuned with new data sets from live drives. Various wireless data uplink methods will be required depending on specific data modalities such as sensor data, vehicle diagnostics, positioning data and real-time situational data.

## 4.6 REAL-TIME HD MAPPING

Real-time HD mapping is a critical ingredient for automated driving, although technical implementation strategies vary. In “map-light” approaches, high-definition maps are primarily used for *navigation* purposes and will be overlaid with real-time situational data (for example, accident notification, road construction).

In “map-heavy” approaches, HD maps play a much more critical role in *path planning*—even to a centimeter level of detail. Such scenarios will require maps that may be up to 1 TB in size for a single city/neighborhood. Not only will these maps need to be updated periodically without direct user interaction, they may even require on-demand updates as vehicles move across geographies. Deployment strategies that leverage roadside infrastructure and edge cloud solutions to deliver these map updates will become crucial to keep costs down.

# 5. STAKEHOLDERS AND THEIR ROLES

## 5.1 MOBILE NETWORK OPERATORS

The mobile network operator’s role within V2X will initially follow an evolutionary pathway built on the role the operator plays with today’s connected car: providing V2N services. This pathway will allow the mobile network to deliver value to vehicles as autonomy increases, including many use cases that require higher bandwidth, lower latency and higher reliability services. Depending on the strategy and approach of the mobile operator, there may be an opportunity to perform V2I services, as well. Similarly, additional opportunities for mobile operators may exist across the modalities of V2V, V2I, V2N and V2P. For these new applications, the business cases and economic value of providing such services will need to be carefully evaluated. In addition, mobile operator delivery of V2V or other safety use cases may be affected by the jurisdiction of, and requirements from, automotive safety regulators.

Today, though, there is an increasing expectation of network connectivity for vehicles, and it is projected that this demand will only grow in the future. Connectivity is demanded not only for critical vehicle functions and improved safety, but also for the delivery of audio, video, social media access and location-based services, among others, in daily driving. Despite such demands for connectivity, there is currently no way for vehicle owners to choose the provider of mobile network connectivity for their vehicles. The connected service packages integrated in vehicles are limited to a single designated provider. This deprives vehicle

<sup>34</sup> [Network World Article](#), December 2017.

owners from the freedom to choose the mobile network that provides the best coverage and quality of service in their area and may result in higher prices. As vehicle connectivity becomes more unified with the safe operation of the vehicle, vehicle owners should have the freedom to choose their mobile network provider, much as they do for their smartphones today. Interoperability of vehicles among available cellular networks not only ensures redundancy for critical safety features but will result in better value and service for consumers via investment incentivized by the competition between mobile network operators.

### **V2V Aspects**

Mobile network operators will not be interacting with the short-range V2V communications, whether it be DSRC or C-V2X. These direct, ad-hoc communications work without network assistance but may benefit from the network assistance with scheduling of resources among vehicles. The vehicle specific information being broadcast and received most often has relevancy within a very small, isolated range. On the other hand, there is also a need for event-driven vehicle sourced data (for example, report of hazards, road work) to be broadcast on a larger (for example, cell-sized) area. Here an operator can rebroadcast a vehicle's report of a hazard to other vehicles nearby but beyond the range of direct V2V communication, such as by using the evolved multimedia broadcast multicast services (eMBMS) system. At this stage, there does not appear to be an economic model that would incentivize mobile network operators to participate in the short-range V2V communications that will exclusively target vehicle safety and crash avoidance.

### **V2I Aspects**

Mobile operators may decide to participate and add value in the V2I communication pathway. This area focuses on providing the V2V-enabled vehicle with a way to provide backhaul for the Security Credential Management System (SCMS)-specific activities including enrollment, Certificate Revocation List (CRL) distribution, certificate top-ups and the communication of misbehavior reports, as well as to support V2I use cases. As currently proposed for V2I as part of the DSRC short-range communication protocol, there is an expectation that eventually, RSUs would need be installed along a significant portion of the nation's roadways to provide this functionality. In urban areas, RSU's could be integrated with existing road infrastructure and utilize established fiber or wireline connectivity. In rural areas, the addition of RSUs would likely be more challenging and may create an opportunity for mobile networks to provide backhaul to these more isolated RSUs.

However, fully deploying a nationwide RSU network represents a significant investment and would require states to invest in resources to build, maintain and operate these networks. This is likely to be a multi-year effort. An alternative approach would be to utilize the existing extensive coverage footprint of mobile networks by moving these communications from V2I to a modality of V2N. In such a scenario, the mobile network operator would be able to communicate the tasks of the RSU over its network, reducing time to market, cost and eliminating the complexity of designing and running a purpose-built network for V2I. Stakeholders such as vehicle OEMs and state highway officials would then interact with mobile operators to both obtain data from the system, as well as provide V2I applications that may be safety-related.

### **V2N Aspects**

Today's mobile networks can support many of the existing V2N use cases. Over time, as new standards are developed and implemented to improve coverage, reliability and throughput, and reduce latency as part of the evolution to 5G, mobile operators will have the capabilities to support more advanced, mission-critical use cases such as remote driving. For such mission-critical use cases, a truly nationwide 5G network will be important in providing the coverage, throughput and guaranteed quality of service that are needed.



Mobile operators could also play a role in the communications needed to manage the transportation infrastructure in conjunction with cities and municipalities. In this expanded capacity, mobile operators could assist with functions such as traffic management and event notifications, leveraging not only a robust network connection but also managing and coordinating the flow of information between vehicles and infrastructure throughout the city or municipality.

Some of the use cases that could be delivered by the mobile network operators via V2N include:

- Distribution of software and firmware updates to vehicles, including HD maps
- SCMS communications and distribution of CRLs
- Macro-level distribution of vehicle event notifications

### **V2P Aspects**

The mobile operator's traditional role of providing the coverage and connectivity for smart devices creates the opportunity to add value by participating and/or facilitating the V2P communication pathway for Vulnerable Road Users (VRUs). These devices in the hands of bikers and pedestrians will have the ability to interact with the mobile network for both sending and receiving messages and alerts. The mobile operator could play an important role in delivering critical alerts that will ensure the safety of the transportation ecosystem participants as they move within their environment. As split-second reactions are needed to avoid a collision, it may be more effective to put the burden of avoidance on the vehicle with its more powerful computing and electronic control systems that could assist the driver in changing course or stopping.

Some of the use cases that could be delivered through V2P include:

- Detecting a pedestrian crossing the road at an intersection or a cross walk
- Detecting a bicycle on a car lane or bicycle lane
- Detecting traffic conflicts, such as car running red light, pedestrian crossing the road during red light

These use cases are particularly useful when the VRUs are hidden from the vehicles and could not be detected by on-vehicle line-of-sight sensors. With V2P, especially when the VRU device can also send periodic safety messages via C-V2X, the hidden VRUs can be detected collaboratively through the exchange of messages between the involved VRUs and vehicles. 5G C-V2X supports unicast, multicast and broadcast communications, so it can support a wide variety of V2P use cases.

## **5.2 VEHICLE MANUFACTURERS**

With the advent of V2X communications and connected vehicles, vehicle manufacturers are learning to expand their collaboration with mobile operators. Some of the decisions they face involve how to securely provision/update their vehicles software, which V2V communications technology to build into their vehicles and which service provider to partner with for added services for their drivers.

The 5GAA counts a host of vehicle OEMs in its ranks. These OEMs are developing test criteria to evaluate 802.11p-based radio access technologies versus C-V2X to comparing link- and system-level performance for both technologies. 5GAA is evaluating how to execute the tests and then share the process and results. This effort is aimed at addressing the question of performance comparison, as this is key decision point for the automotive community.

Other decision points include the relative cost of a standalone 802.11p transceiver versus the expected integrated C-V2X and cellular modem telematics control unit solution, considerations transition to 5G NR from each of the two radio access technologies, the realistic relative potential for UEs to be on the roadside and the availability of the C-V2X technology versus largely regulatory timelines. All these considerations will be carefully considered because the first technology to achieve widespread market acceptance will likely remain in cars for a great many years due to desire for new generations to be interoperable with older generations.

5GAA published a study,<sup>35</sup> “The cost-benefit analysis on cellular vehicle-to-everything (C-V2X) technology and its evolution to 5G-V2X,” showing a net benefit in 2035 of up to €43 billion. This report, authored by independent telecoms, media and technology consultants Analysys Mason, together with automotive consultancy SBD Automotive, assesses the benefits of C-V2X technology for V2X. The report, which has a focus on the benefits of such solutions in Europe, uses qualitative evidence and describes quantitative cost–benefit analysis that the consultants have undertaken, relating to deployment of C-V2X.

Vehicle OEMs and suppliers participate in C-V2X trials in the U.S., Europe and other regions. In the U.S., radio-level testing for cellular V2X<sup>36</sup> is planned in Michigan by Ford Motors and Qualcomm Technologies, Inc. Another trial<sup>37</sup> was announced for San Diego, California. In Europe, there are C-V2X Release 14 trials underway in Germany, France and the U. K.<sup>38</sup> For example, in the Connected Vehicle-to-Everything of Tomorrow (ConVeX) trial,<sup>39</sup> the aim is to demonstrate the compelling benefits of a unified C-V2X connectivity platform for the connected vehicle of tomorrow, as well as to showcase C-V2X range, reliability and latency advantage for real-time V2X communications. Trial results are to be used to inform regulators, provide input to ongoing global standardization effort and shape a path for the evolution of C-V2X technology.

### 5.3. THE ROLE OF CLOUD SERVICE PROVIDERS

Cloud service providers’ role in V2X could increase with 5G. They already support mobile operators by offering global SIM card management for connected cars and ecosystem management, and by providing data centres that complement operators’ clouds and edge clouds. In parallel, a number of car manufacturers are signing up contracts with cloud service providers to host or leverage data collection-management and analytics platforms, as well as API management and ecosystem management platforms. With 5G and more dynamic networks, more open ecosystem, less predictable traffic, the role of cloud service provider could increase to supplement network operators’ capabilities.

### 5.4. SPECTRUM AND REGULATORY ASPECTS

Internationally, advanced automotive systems are also referred to as Intelligent Transportation Systems (ITS).

Developments in Cooperative ITS (C-ITS) internationally have been the catalyst for the advance consideration of regulatory arrangements for these systems. There has been significant progress in several regions, most notably in Europe, the U.S. and Japan. International organizations that consider spectrum harmonization efforts, such as the International Telecommunication Union (ITU), European Conference of

<sup>35</sup> 5GAA, [The cost-benefit analysis on cellular vehicle-to-everything \(C-V2X\) technology and its evolution to 5G-V2X](#), December 2017.

<sup>36</sup> Ford Motor Company, [On the Road Towards LTE-V2X](#), 2017.

<sup>37</sup> Qualcomm [Press Release](#), October 2017.

<sup>38</sup> [ITS World Congress](#).

<sup>39</sup> IEEE Connected Vehicles, [Connected Vehicle to Everything of Tomorrow](#), January 2017.

Postal and Telecommunications Administration (CEPT) and Asia Pacific Telecommunity have also started considering ITS systems as a whole and, more specifically, C-ITS systems in the 5.9 GHz band.

Global ITS spectrum is currently under further study within ITU-R Working Party 5A, responsible for studies related to land mobile service, excluding IMT and including wireless access systems such as RLANs and ITS. The latter is considered essential in improving the safety and efficiency of roads and highways. Specifically, the ITU World Radio Conference 2015 (WRC-15)<sup>40</sup> adopted a resolution to include a new agenda Item at the WRC-19 “to carry out studies on technical and operational aspects of evolving ITS implementation using existing mobile-service allocations in advance for WRC-19.”

In the U.S., the channel allocation for DSRC is specified in FCC 47 Code of Federal Regulations (CFR) Parts 0, 1, 2, 90 and 95 amendments for “Dedicated Short-Range Communications Services and Mobile Service for Dedicated Short-Range Communications of Intelligent Transportation Service in the 5.850-5.925 GHz Band (5.9 GHz Band).”<sup>41</sup>

The FCC released a public notice on June 1, 2016, to refresh its record on the potential for spectrum sharing between proposed Unlicensed National Information Infrastructure (U-NII) devices and DSRC operations in the 5.850-5.925 GHz (U-NII-4) band. The spectrum-sharing consideration is based on whether unlicensed operations can be supported while maintaining interference protection for incumbent federal and nonfederal users. The FCC has recently performed testing techniques for spectrum sharing between U-NII devices and DSRC operations in the ITS band. The test report is expected to be available by the end of 2017, while the date for any Report and Order is not available at present.

In Europe, member states are required to designate and make available the 5875-5905 MHz band for safety-related aspects of ITS.<sup>42</sup> Investigations into spectrum requirements for ITS service concluded that 30-50 MHz within the 5.9 GHz band is required for road safety and traffic efficiency, including an exclusive 30 MHz for time-critical road safety applications, as well as 20 MHz for future ITS applications.<sup>43</sup> Furthermore, ECC Recommendation (08)01<sup>44</sup> addresses frequency usage for ITS non-safety applications at 5855-5875 MHz on a non-protected and non-interference basis.

It should be noted that these legislations are technology neutral. However, this estimate does not include additional forward-looking ITS applications, such as those that may require 5G technologies, for which alternatives such as the 63-64 GHz band may be appropriate. Channeling arrangements are defined by ETSI EN 302 571.<sup>45</sup>

In March 2016, the amended ECC Decision (09) 01<sup>46</sup> decided that CEPT administrations shall designate the 63-64 GHz band for ITS applications, with the purpose “to reduce the number of traffic fatalities and improving the efficiency of traffic using inter vehicle or infrastructure to vehicle communications including hybrid radar and vehicle communications systems.” To date, this decision has been implemented by 36 countries. There is strong interest in using this frequency band for C-ACC and platooning applications owing to the wide bandwidth available.

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<sup>40</sup> See [https://www.itu.int/dms\\_pub/itu-r/oth/0c/0a/R0C0A00000C0013PDFE.pdf](https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0013PDFE.pdf)

<sup>41</sup> <http://www.gpo.gov/fdsys/pkg/FR-2006-09-07/pdf/E6-14795.pdf>

<sup>42</sup> Arrangements for C-ITS systems at 5.9 GHz have been in place since 2008 with the European Commission Decision, 2008/671/EC on the harmonized use of radio spectrum in the 5875-5905 MHz band. For additional information, see <http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008D0671>

<sup>43</sup> Investigated was done within CEPT (representing 48 EU member states) and the results are summarized in the ECC Decision (08)01. For additional information, See <http://www.erodocdb.dk/docs/doc98/official/pdf/ECCDec0801.pdf>

<sup>44</sup> See <http://www.erodocdb.dk/docs/doc98/official/pdf/REC0801.pdf>

<sup>45</sup> <http://standards.globalspec.com/std/1634935/etsi-en-302-571>

<sup>46</sup> See <http://www.erodocdb.dk/docs/doc98/official/pdf/ECCDEC0901.pdf>

On October 18, 2017, the Radio Spectrum Committee (composed of the commission and the member states) approved a new mandate to CEPT to study the extension of the ITS-safety related spectrum band at 5.9 GHz by 30-50 MHz. The mandate importantly recognized the recent developments and standardization of LTE-based V2X for ITS applications, which could underpin the path to 5G connectivity for the automotive/road transport sector. The mandate includes two main study requirements: the inclusion of urban rail (CBTC) in this ITS band in the upper part of the band (5905 – 5925 MHz), and the coexistence between ITS-G5, LTE-V2X and Communications-Based Train Control (CBTC). CEPT should deliver the final report by March 2019.

## ANNEX: NPRM RESPONSE SUMMARY

In response to NHTSA's NPRM on FMVSS 150 – V2V Communications (Docket No. NHTSA-2016-0126) 456 comments were filed; 77 were substantive, while most of the remainder were individuals opposing the proposal based on RF exposure and/or privacy concerns. Note that the NPRM covers only V2V communications required for safety, and although it opened the door somewhat for other technologies, its emphasis is on DSRC.

Comments were filed by a wide variety of parties, including automotive OEMs, automotive suppliers, industry/trade associations, governmental organizations, public safety organizations and public interest advocacy groups.

### Automotive OEMs

Nine auto OEMs filed their own comments, in addition or to supplement those filed by their respective trade associations (the Alliance and Global).

Many major manufacturers (GM, Ford, Toyota, VW Group, Mazda, FCA (Fiat Chrysler Automobile)) expressed support for the NPRM, and provided varying suggestions for changes prior to a final rule. Ford and other OEMs suggested a three-year lead-time (instead of two) with lower phase-in percentages over four years (instead of three). Ford also stated that it expects that C-V2X technology will be available in the proposed NPRM deployment timeframe and that it intends to conduct field trials over the next year to continue validating its performance capabilities and anticipates to share its learnings with NHTSA. Other OEMs such as GM strongly supported DSRC due to its maturity and demonstrated capability to meet near term V2V requirements. FCA supported the Alliance comments, but indicated a lack of enthusiasm for V2V communications of any sort, and instead a preference for achieving safety gains through vehicle resident systems.

BMW and Mercedes explicitly referenced and supported the comments of 5GAA, and recommended technological neutrality in a final rule mandate in order to allow for C-V2X. Mercedes uniquely went so far as to prefer the “if-equipped” alternative proposal to the primary mandate. Tesla opposed the rulemaking outright, preferring AV systems to provide safety benefits, and arguing that complying with a V2V rule will divert auto OEMs' resources away from newer technologies. It did offer several recommendations to change the proposed rule, on the assumption that NHTSA proceeds with a rulemaking.

Virtually all OEMs argued that NHTSA should verbatim adopt and/or incorporate by reference the most current and pertinent SAE standards governing BSMs and other DSRC elements, rather than adapt those standards with some of the unique regulatory language that deviates from the standards that is presented in the NPRM.

### Automotive Suppliers and Other Adjacent Industry Companies

Comments were filed by 13 automotive components/technology/services suppliers, four connectivity providers (AT&T, Verizon, Inmarsat and SiriusXM), Broadcom, Cisco, Qualcomm Incorporated and Waymo (Google).

There was some diversity among the suppliers. Panasonic, NXP, ZF, Denso, Delphi, Infineon, Peloton Technology and u-blox all supported DSRC and tended to provide some technical comments on details of the NPRM. LG supported the NPRM but recommended a dual-DSRC-LTE requirement. HERE advocated for a cellular-based approach rather than the proposed DSRC approach, as did both HAAS Alert and Nexar.

Among the connectivity providers, Inmarsat and SiriusXM both supported the NPRM and argued that satellite connectivity should play significant roles in supporting the NPRM's objectives. Verizon endorsed the 5GAA's critiques of the NPRM, arguing the merits of C-V2X over DSRC, and that the NHTSA should not mandate a technology. AT&T generally supported the proposed V2V communications mandate but took no position on DSRC versus C-V2X as the technological basis for V2V communications. AT&T recognized that DSRC is proven to meet the performance requirements of the proposed mandate and the associated applications expected to use the communications, but counseled that C-V2X is likely to demonstrate improved performance in some respects relative to DSRC, within the timeframe of the final rulemaking, and suggested that the NHTSA closely track the development of this technology while it continues to pursue the rulemaking.

Qualcomm Incorporated argued for changing the NPRM to be more technologically neutral and enabling interoperability between DSRC and C-V2X. Cisco echoed this to an extent, but advocated moving forward with DSRC while developing a migration strategy to other technologies, should they (therefore, C-V2X) prove later to be viable and better options. Broadcom opposed the NPRM and reprised arguments over the 5.9GHz spectrum it has made at the FCC.

Waymo neither supported nor opposed the NPRM *per se*, but rather focused its comments on the relationship between prospectively required V2V communications and automated vehicles.

## **Industry and Trade Associations**

There were 23 trade associations that filed comments, with most representing a variety of factions within the automotive industry. Comments from the 5GAA, Cellular Telecommunications Industry Association (CTIA), NGMN, the Wi-Fi Alliance and National Cable Television Association (NCTA) were submitted representing various sets of communications companies, and CTIA provided limited comments addressing jurisdictional concerns pertaining to aftermarket electronic devices.

The 5GAA, 5G Americas and NGMN provided arguments pertaining to C-V2X technology, and its relative merits over DSRC, and generally argued that any rulemaking should be technologically neutral, rather than *de facto* requiring DSRC. However, in their filing, they do not truly address whether or how DSRC and C-V2X could be interoperable with each another.

Most organizations provided at least some degree of support for NHTSA's rulemaking, with the major U.S. automotive OEM trade groups (the Alliance and Global) providing substantive support and relatively detailed recommendations for changes—including issuance of a Supplemental NPRM (SNPRM) to address what they perceive as several areas insufficiently addressed by the NPRM. Global Automakers was more directly supportive of mandating DSRC in the NPRM, and has been very publicly active on the issue of the 5.9 GHz spectrum sharing, seeking to protect it for V2V use. The Alliance (with BMW and Mercedes-Benz as members, and with no supplier members) supported DSRC but with an acknowledgement of a desire for interoperability with other technologies.

Other automotive industry associations also generally provided support for DSRC and the proposed mandate, including the Intelligent Transportation Society of America (ITSA), American Trucking Associations (ATA), American Motorcyclist Association (AMA), Automotive Safety Council (ASC), Specialty Equipment Market Association (SEMA), IEEE 1609 Working Group, SAE DSRC Committee and OmniAir. ITSA did advocate for technological flexibility to allow for 5G in the future. Interestingly, the Car-2-Car Connectivity Consortium (C2C-CC), a European group representing a broad range of auto OEMs also explicitly and strongly supported DSRC—despite counting among its members BMW, Daimler, and Ford who are the most strongly in favor of C-V2X and antagonistic toward DSRC.

NCTA (representing cable providers) argued that NHTSA should not pursue the rulemaking. This is in line with its advocacy at the FCC on the 5.9 GHz issue, as cable companies are seeking access to that spectrum for Wi-Fi usage.

### **Public Interest/Advocacy Groups**

Ten public interest/advocacy groups filed comments, including four generally left-of-center organizations, four generally right-of-center think tanks and the Future of Privacy Forum.

The Electronic Frontier Foundation (EFF) and Electronic Privacy Information Center (EPIC) each raised concerns about the privacy and security components of the NPRM, and proposed changes to address those; EFF generally opposed proceeding with the rulemaking. Consumers Union strongly supported the rulemaking and urged a *quicker* than presented time line for adoption, though somewhat contradictorily also suggested that NHTSA remain open to technologies other than DSRC. The National Safety Council (NSC) strongly supported the rulemaking.

Each of the right-of-center organizations strongly criticized the NPRM, generally arguing that it eschews market driven development and adoption of technology and was adopting a technology likely to be outmoded in the future.

A number of individuals strongly opposed the NPRM on the grounds that the rules violated individual privacy and unnecessary over reach of the government.

### **Government Organizations**

The National Transportation Safety Board, was the only federal entity to file comments, and it strongly supported NHTSA's NPRM. It suggested that NHTSA consider a means of recording V2V data to support crash investigations (beyond the existing electronic data recorders) but did not address any privacy related implications of this suggestion.

The American Association of State Highway Transportation Officials (AASHTO), the organization collectively representing all state departments of transportation, and the Association of Metropolitan Planning Organizations (AMPO), representing local transportation planning entities, both filed comments strongly supportive of the NPRM. Nine individual state DoTs (Connecticut, Massachusetts, Michigan, Oregon, Pennsylvania, Texas, Utah, Virginia, Wyoming) also filed comments, generally endorsing and augmenting the views expressed in AASHTO's comments. Texas DoT, in addition to supporting DSRC, recommended that NHTSA address the use of connectivity provided by other technologies (for example, 5G) as an alternative to DSRC. The state comments often addressed the implications of the V2V rule for state deployment and use of V2I infrastructure elements and were supportive of the rule as a means to help drive infrastructure deployment. Additionally, each of these comments supported the "two-radio" DSRC based approach discussed in the NPRM (therefore, one DSRC radio used for V2V Basic Safety Message (BSM) transmission, and a second used for other V2X purposes).

## 6. CONCLUSION

The connected car market is already a mainstream reality; it is leveraging cellular connectivity to provide telematics, connectivity and improved use experience. The vision to go beyond cellular connectivity towards V2X communication is also becoming a reality.

The V2X communication based on LTE has already been standardized by 3GPP Release 14. Now automotive manufacturers, chip providers, network equipment providers and network operators along with network operators/communication service providers are already completing trials in the U.S. and Europe.

The 5G-based V2X solutions that 3PP is working towards standardizing aim to provide advanced V2X use cases leveraging the enhancement that 5G will bring to the radio access and network infrastructure. With 3GPP Releases 15 and 16, 5G will add advanced V2X features with longer range, higher density, very high throughput and reliability, sub-meter positioning and ultra-low latency. The basic safety services for which Release 14 LTE-based V2X was designed will remain an integral part of the V2X communication ecosystem.

The paper calls for action by mobile network operators, vehicle manufacturers, cloud service providers and regulatory bodies to work together to accelerate the realization of the advanced V2X solutions based on 5G to deliver a brand-new experience for drivers, travelers and other road users in the near future.



## APPENDIX A: ACRONYM LIST

3GPP	Third Generation Partnership Project
5G	Fifth Generation
5GC	5G Core Network
ACMA	Australian Communications and Media Authority
ADAS	Automated driving and Advanced Driver Assistance Systems
AEVW	Approaching Emergency Vehicle Warning
BRR	Bureau of Radio Regulation
BSM	Basic Safety Message
C2C-CC	Car to Car Communications Consortium
C-ITS	Cooperative ITS
CACC	Cooperative Adaptive Cruise Control
CAMP	Crash Avoidance Metrics Partnership
CCH	Control Channel
CEN	European Committee for Standardization
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CWW	Cooperative Weather Warning
D2D	Device to Device
DOT	Department of Transportation
DSRC	Dedicated Short Range Communication
EEBL	Emergency Electronic Brake Light
EEI	Energy Efficient Intersection
eMBMS	Evolved MBMS
eNB	Enhanced Node B
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FMVSS	Federal Motor Vehicle Safety Standards
GCSE	Group Communication System Enablers
GM	General Motors
HARQ	Hybrid Automatic Repeat Request
ICV	Intelligent Connected Vehicles
IEEE	Institute of Electrical and Electronics Engineers
IMSI	International Mobile Subscriber Identity
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
IVI	In Vehicle Information
IVS	In Vehicle Signage

LTE	Long Term Evolution
LTE-V	Long Term Evolution-Vehicular
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Services
MHz	Megahertz
MIIT	Ministry of Industry and Information Technology
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
NHSTA	National Highway Safety Transportation Administration
NFV	Network Functions Virtualization
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open Systems Interconnection
PKI	Public-Key Infrastructure
ProSe	Proximity Service
PVD	Probe Vehicle Data
QoS	Quality of Service
RHW	Road Hazard Warning
RLW	Red Light Violation Warning
RSU	Road Side Unit
RWW	Road Works Warning
SAE	Society of Automotive Engineers
SCH	Service Channel
SCMS	Security Credential Management System
SDN	Software Defined Networking
SDO	Standards Development Organization
SMVW	Slow Moving Vehicle Warnings
SPaT	Signal Phase and Timing
SVI	Stationary Vehicle/trailer Information
TC	Technical Committee
TJAM	Traffic Jam Ahead Warning
TS	Technical Specification
U-NII	Unlicensed National Information Infrastructure
UE	User Equipment
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User

VSC3	CAMP Vehicle Safety Communications 3 Consortium
WAN	Wireless Access Network
WAVE	Wireless Access in Vehicular Environments
WSMP	WAVE Short Message Protocol

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The contents of this document reflect the research, analysis, and conclusions of 5G Americas and may not necessarily represent the comprehensive opinions and individual viewpoints of each particular 5G Americas member company.

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